

## **Final Report**

### ***Fish Passage System-wide: Hydroacoustics***

Agreement between Penobscot River Restoration Trust and the University of Maine  
Project Period: 26 October 2009 – 11 June 2011

Prepared for the  
Penobscot River Restoration Trust

by  
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#### **Abstract**

Dam removals and passage improvements by the Penobscot River Restoration Project are anticipated to improve connectivity and access for diadromous fish species in New England's second largest river. To assess changes in the fish community, we are using fixed location, side-aspect acoustics to estimate the number of fish passing a designated location below the head of tide on the Penobscot River, Maine. Our methods are similar to other North American efforts, however pronounced (3 m) tidal range and tight restrictions on capture sampling (due to federally listed species) pose unique challenges. In fall 2009 the lower Penobscot River was surveyed for an appropriate location to install acoustic systems. Since May 2010 (excluding months of ice cover) two Biosonics DTX, 200 kHz, split beam transducers, have been mounted on opposite sides of the river (at rkm 35 near Hampden and Brewer) sampling fish passing perpendicular to flow.

Acoustic signals used to count fish must be validated and the entire river cross section cannot be sampled due to the difference in river shape and acoustic beam shape, therefore counts must also be extrapolated to estimate passage through the entire river cross section. As such, complementary sampling with Dual Frequency Identification Sonar (DIDSON) is being used to validate acoustic targets as fish and extrapolate counts to the river cross-section. DIDSON data also provide realistic imaging such that physical and behavioral characteristics may be used for taxonomic discrimination.

We are now in year 3 of the acoustic system and complementary sampling. We have been continuously recording fish activity each April – November. Data ancillary to this project are also being used to verify/validate fish counts and identifications. Several techniques have been used to attempt to validate acoustic targets (fish species) in the split beam: boat electrofishing, acoustic and radio tag data of fish moving through the lower river, fish collected in the Veazie fish trap, and mobile DIDSON surveys. The utility of each of these is discussed.

Methods for site selection and preliminary fish passage estimates from 2010 and 2011 are reported. Lessons learned from 2010 and 2011 informed installation and designs for additional sampling in 2012. Results from this work provide an approach for estimating the number of migratory fish in the river before and after river restoration, independent of a dam structure.

***Project Timeline and Report Format:***

I.	<b>System Design and Deployment</b>	September 2009- April 2010
II.	<b>Design and Installation</b>	
	a. <i>2010</i>	April – November 2010
	b. <i>2011</i>	December 2010 - June 2011
III.	<b>American Shad Sensitivity to Acoustic Sampling</b>	2010 and 2011
IV.	<b>Estimating numbers of targets moving upstream</b>	2010 and 2011
	a. <i>Tracking Fish with Split-Beam SONAR</i>	
	b. <i>Estimates for 2010 and 2011</i>	
V.	<b>Ongoing work</b>	2011 - present
	a. <i>Validation of Fish Counts</i>	
	b. <i>Extrapolation of Fish Counts</i>	
	c. <i>Identification of Targets and Taxonomic Apportionment of Fish Counts</i>	
	d. <i>Modeling Flow Velocity and Direction</i>	
VI.	<b>References</b>	
VII.	<b>Book-keeping</b>	
	a. <i>Project PI time</i>	
	b. <i>Part-time assistance</i>	
	c. <i>List of items worth over \$300</i>	
VIII.	<b>Appendix 1: Description of BioSonics data processing</b>	

***Proposed Project Objectives:***

- 1) Establish split beam hydroacoustics as a long-term assessment tool for determining numbers of upstream and downstream migrating diadromous fishes in the Lower Penobscot River.
- 2) Determine numbers of individual upstream and downstream moving targets and discriminate by species as possible.
- 3) Determine validation needs of hydroacoustic systems.

***Proposed Outcomes:***

- 1) A standardized, quantifiable assessment tool for migratory fish counts pre and post river restoration activities.
- 2) The impact of dam de-construction on the extent of fish presence in the lower river will be assessed.

## **I. System Design and Deployment**

In Fall 2009 a hydroacoustic system manufacturer, BioSonics, Inc., was contracted to help locate a fish monitoring system in the lower Penobscot River. The contract specified a complete system with one hydroacoustic unit on each side of the river, arranged to form an acoustic curtain across the river, through which most of the upstream migrating fish would pass, allowing them to be detected and recorded. Major considerations prior to surveying were: tidal fluctuation (up to 4 m); shad/alewife sensitivity to certain acoustic frequencies; uncertain use of the river by the fish (bottom/water column, bank/channel); and how to mount the system securely and near a power source. As such, the three major objectives of the fall survey were to:

- (1) Test different hydroacoustic frequencies
  - a. to establish the size of a possible acoustic curtain at two different frequencies
  - b. in consideration of sensitivity of shad/alewife
- (2) Document river morphology at different sites
  - a. to determine the beam angles that could be achieved
  - b. to determine how much river can be covered during different tidal stages
- (3) Identify a secure location with power

Surveys were conducted in October 2009 with BioSonics, Inc. They were designed and conducted close to sources of power, to assess acoustic qualities of the river and test the distance across the river that could be sampled using acoustic transducers that produced sound on the edge of shad hearing range (200 kHz) and outside of their hearing range (420 kHz). Knowing the latter transducer would be the limiting condition, the survey was conducted with a 420 kHz transducer.

### *Methods:*

Five sections of the river were surveyed in detail (Figure 1). Surveys consisted of transects across the river (Figure 2) with the acoustic transducer aimed at the bottom to collect river depth to document morphology (Figure 3). Additional surveys were conducted with the transducer positioned horizontally to determine distance across the river that could be covered.

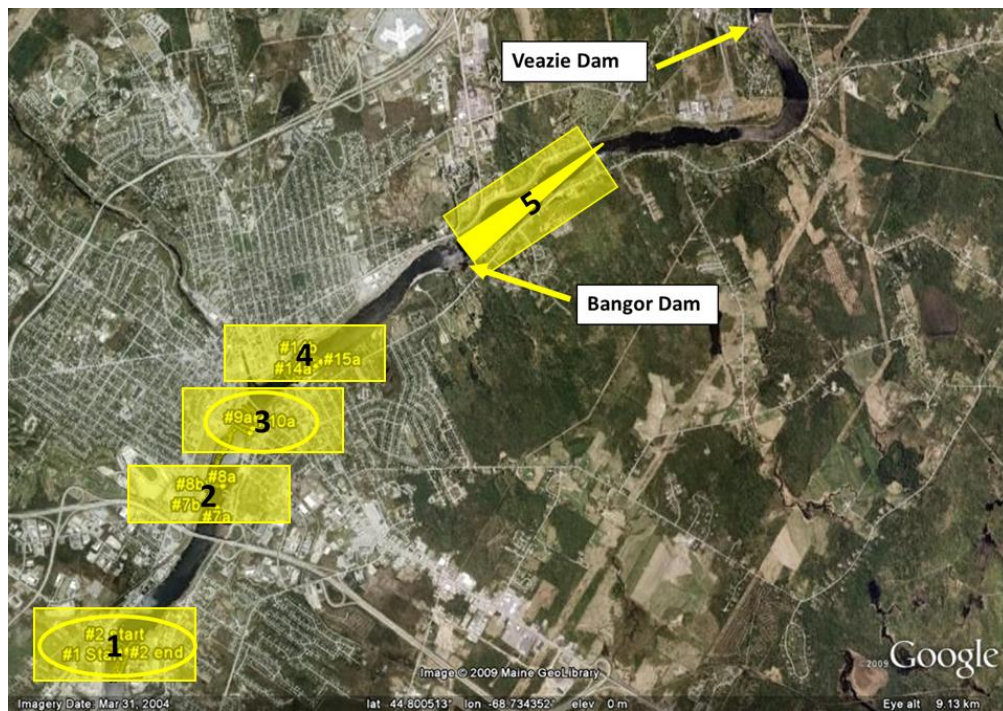


Figure 1. Sections of the lower Penobscot River that were surveyed with a BioSonics 420 kHz split beam echosounder in Fall 2009.

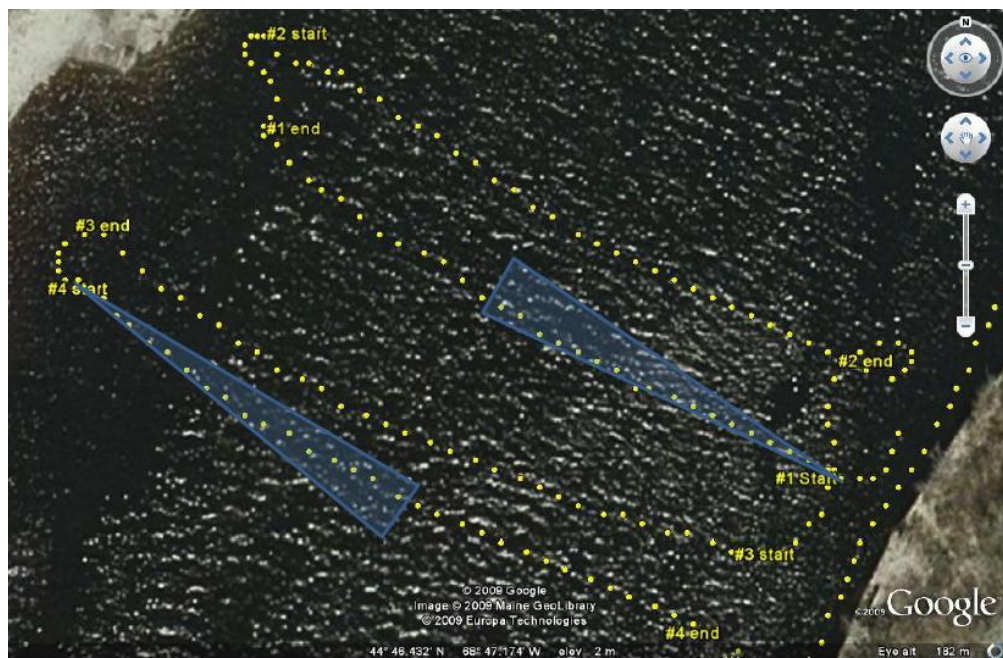


Figure 2. Representative transect points (yellow circles) used to determine bottom bathymetry in area 1 of Figure 1. Blue triangles are possible cones of ensonification (curtains) for a 200 kHz split-beam SONAR positioned at the pointed end of each triangle.

## Results

It was determined that the 420 kHz transducer would only detect large fish at a maximum distance of 45 m (approximately one-quarter the distance across the average river width, Figure 3). The sites upstream of the Bangor dam (region 5 on Figure 1) were considered uniformly too shallow and unsuitable for hydroacoustic monitoring. Tidal impacts near the Bangor waterfront (Figure 1 area 3) limited the range of detection across the river (Figure 4) due to the narrowly sloping river bank on the east.

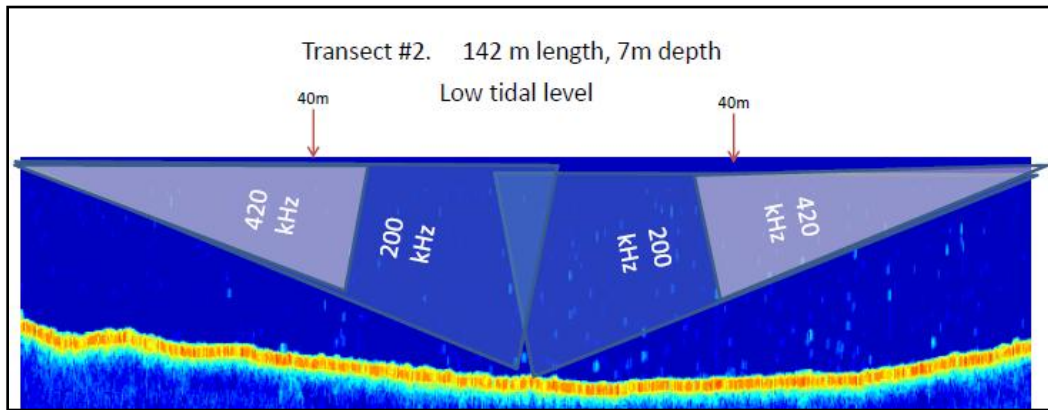


Figure 3. River cross section in area 1 of Figure 1. The red line represents the bottom of the river. Theoretical conical acoustic beams are shown for each of 420 and 200 kHz transducers.

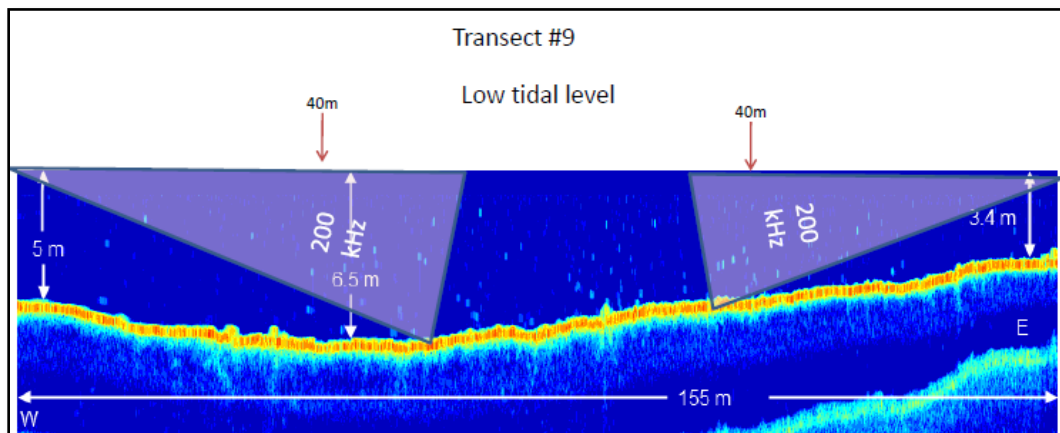


Figure 4. River cross section in area 3 of Figure 1. The red line represents the bottom of the river. Theoretical conical acoustic beams are shown for two 200 kHz transducers. The range is boundary limited because it impinges on the surface or bottom.

### *Implications to project*

The final site chosen for deployment was area 1 (in Hampden/Brewer, HamBrew, near the Cianbro manufacturing facility and Waterfront Marine) because of the potential coverage of more river volume during both low and high tides. Also, because river coverage would be greatly reduced with installation of 420 kHz transducers, 200 kHz transducers were leased in year 1 (Jan 2010 – Dec 2010) to provide an opportunity to assess the response of American shad to this frequency. There was then the option to purchase either 420 or 200 kHz transducers during year two. A controlled study was also designed to examine shad behavioral responses in other river systems (see Section III).

### Landowner Coordination

Once the site was chosen meetings were arranged with representatives of Cianbro Constructors and Waterfront Marine to outline the project and request permission to install hydroacoustic equipment on their properties. Both parties were eager to assist. In addition to granting access, they volunteered several hours of staff time and equipment. Cianbro installed a catwalk that extends over the river's edge, a small shelter to house equipment, and ran power lines to the site. The Waterfront Marine donated a 2 ton concrete mooring (the base for our transducer mount on that side of the river) and has been deploying and retrieving this annually using their specialized lift barge. Both parties have been donating the cost of electricity to run the systems and have granted us access to their properties and wireless networks which allows us to remotely access and manage our equipment.

## II. Design and Installation

BioSonics, Inc. equipment was purchased/leased in January 2010. Several additional meetings were held with the two landowners to discuss details of mounting and powering the systems. A mounting solution (Figure 5) was developed in consultation with BioSonics, Inc. and engineers at Cianbro. Aiming of the SONAR transducer (Figures 6 & 7) is essential to collecting quality acoustic data and the designed mount allows manual adjustment of depth, bearing and pitch. We purchased the materials and fabricated the mounts. A field scientist from BioSonics, Inc. was on-site to assist with installation and training the week of 26-30 April 2010 and the systems were installed on 27 April. Figures 8 - 10 show the location and layout of the study site.

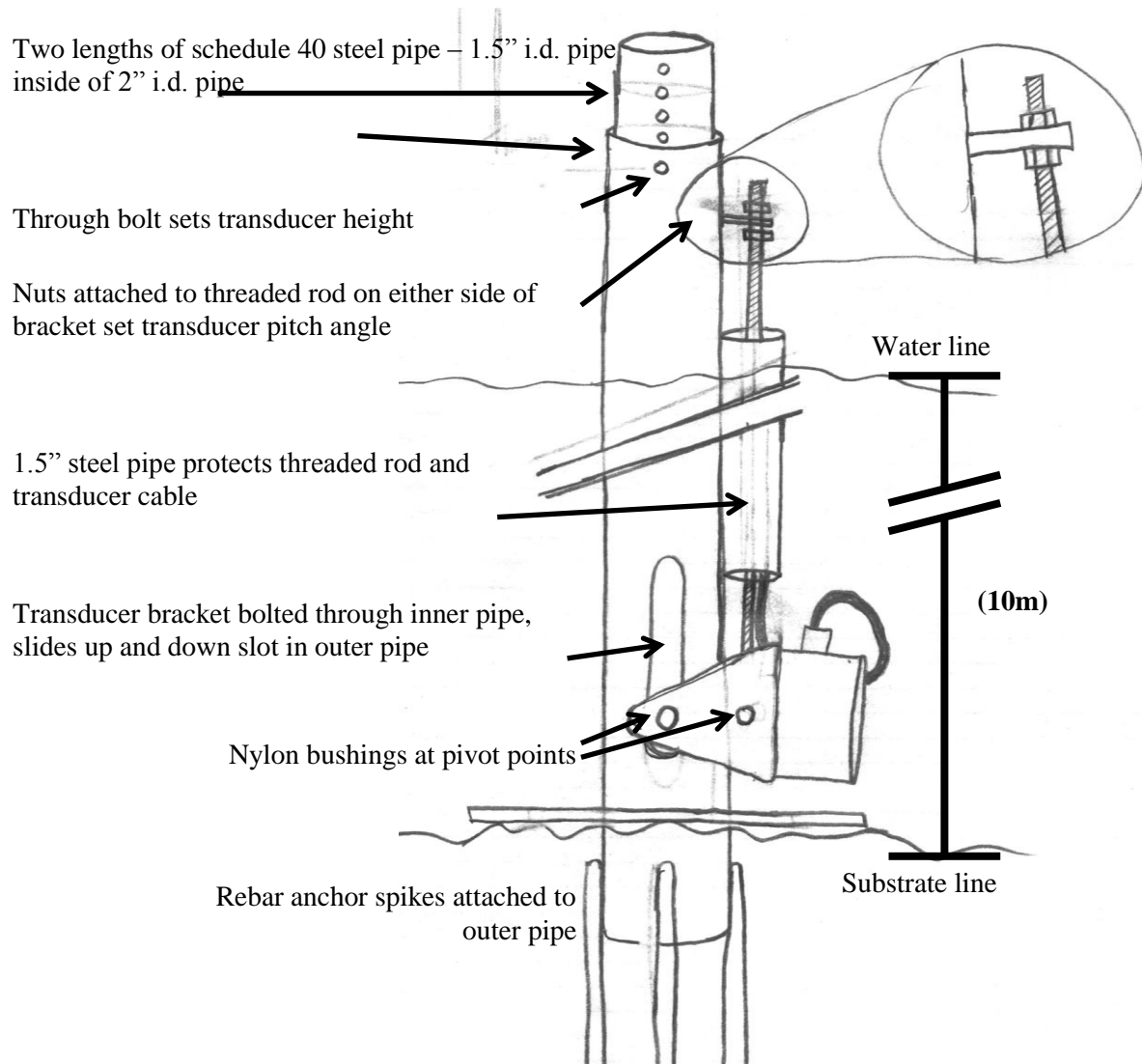


Figure 5. Line drawing showing details of manually adjustable transducer mount.

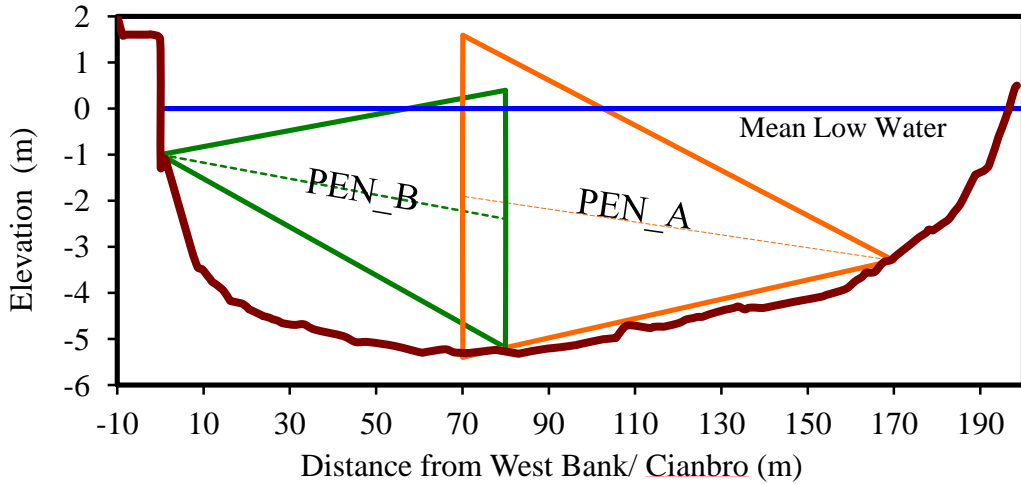


Figure 6. Cross section of the HamBrew hydroacoustic sample site. Triangles approximate the volume sampled by two split-beam 200 kHz transducers (PEN\_A and PEN\_B). Note the height (radius) of the acoustic beams increase with range. This reduces detectability at short range (blind spots above and below) and long ranges where the beams ultimately intersect the river bottom or surface (depending on aim/pitch angle).

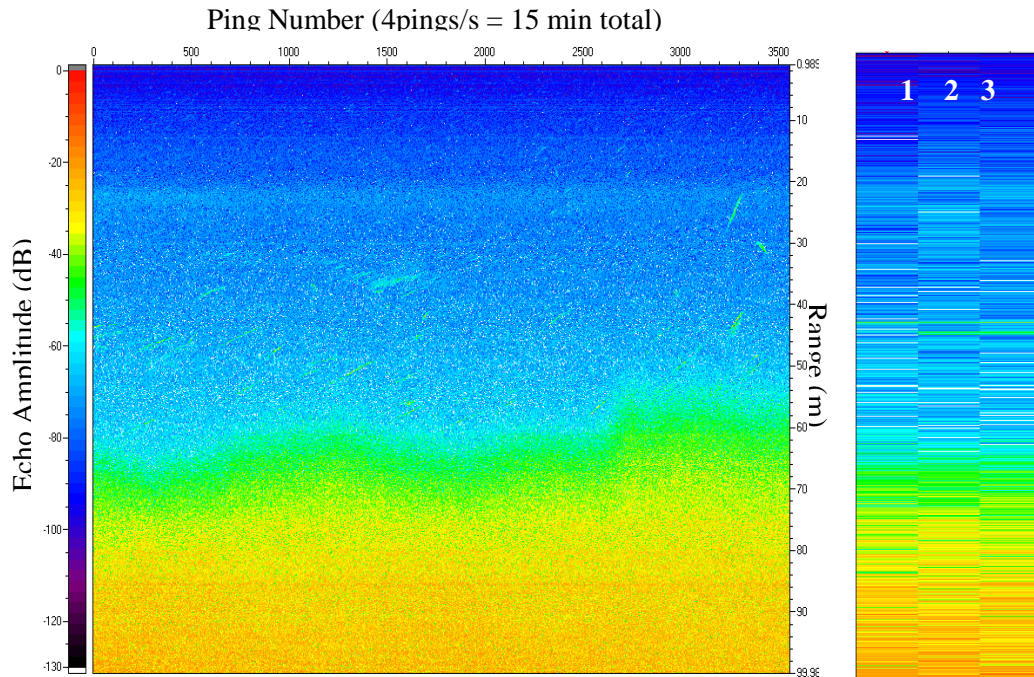


Figure 7. An example echogram of 15 minutes of data from one of the split-beam systems. Green and yellow bands at 60 – 100 m range are reflections from the river's surface. A faint but consistent red line at ~85m indicates a reflection from a fixed object on the river bottom. The fine blue/green diagonal lines at <60m range are fish tracks. A magnified view of 3 pings is in the right panel. Colors represent echo amplitude received from each range increment (rows) within each ping (columns), creating a grid of values.

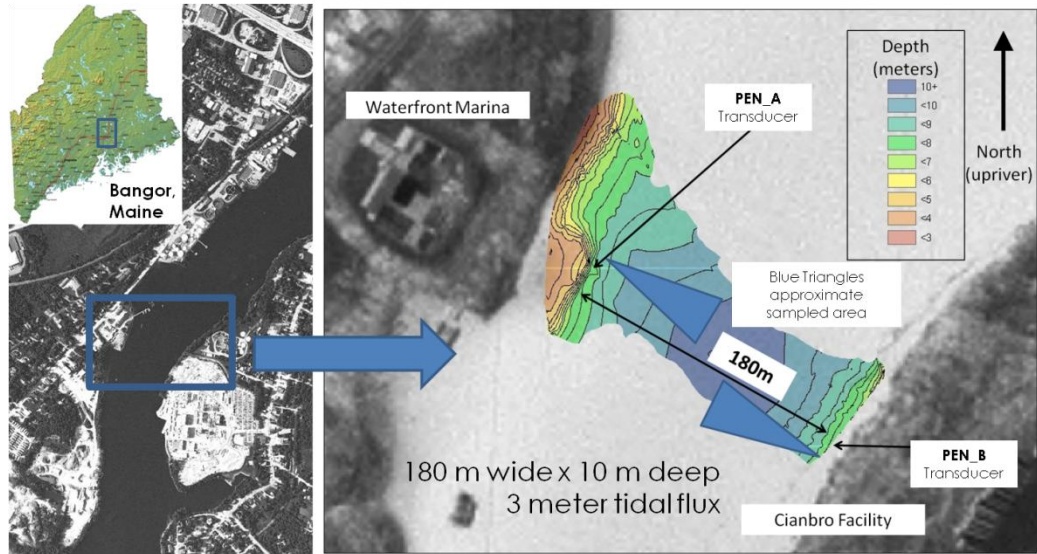


Figure 8. Location and bathymetry of “HamBrew” sampling transect. The blue rectangle on the inset map indicates the location of Bangor, ME. The blue rectangle in the aerial photograph in the left panel indicates the location of the hydroacoustic site at the Hampden (west shore) and Brewer (east shore). Blue triangles approximate area of the river sampled by the two systems (Pen\_A and Pen\_B). The site is approximately 180 m wide and 10 m deep with a 3 m tidal fluctuation.

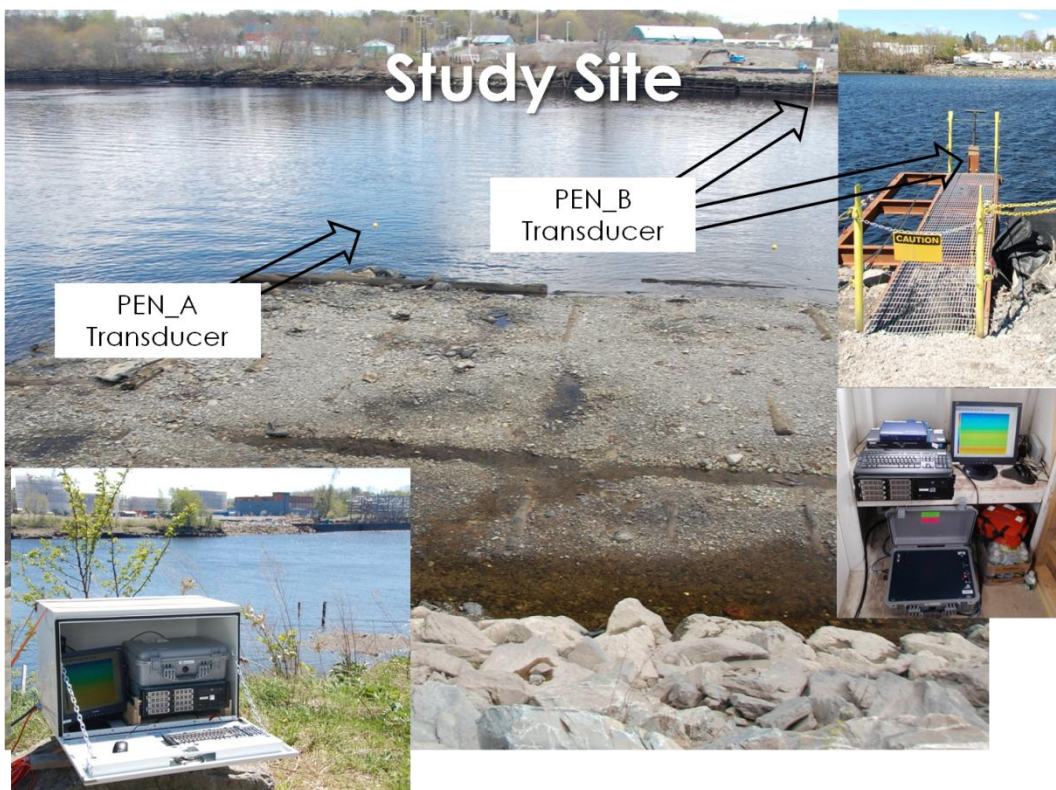


Figure 9. Image of HamBrew at low tide showing locations of transducers. Inset photographs show catwalk and topside hardware/enclosures.

*a. 2010*

After installation on 27 April, the aim of the transducers was adjusted several times to minimize returns from obstructions and the river's surface (Figures 6 & 7). In June, a site visit from two hydroacoustic experts, Don Degan and Anna Maria Mueller of Aquacoustics, led to further refinements in aim and collection parameters. They also suggested that elliptical beams with a narrower (4 vs. 6 degree) vertical angle might be better suited to the site than the circular beam in use at the time (Figure 10). They sent us one of their elliptical transducers and after testing the two beam geometries side-by-side we determined that the elliptical beam was better suited for our application.

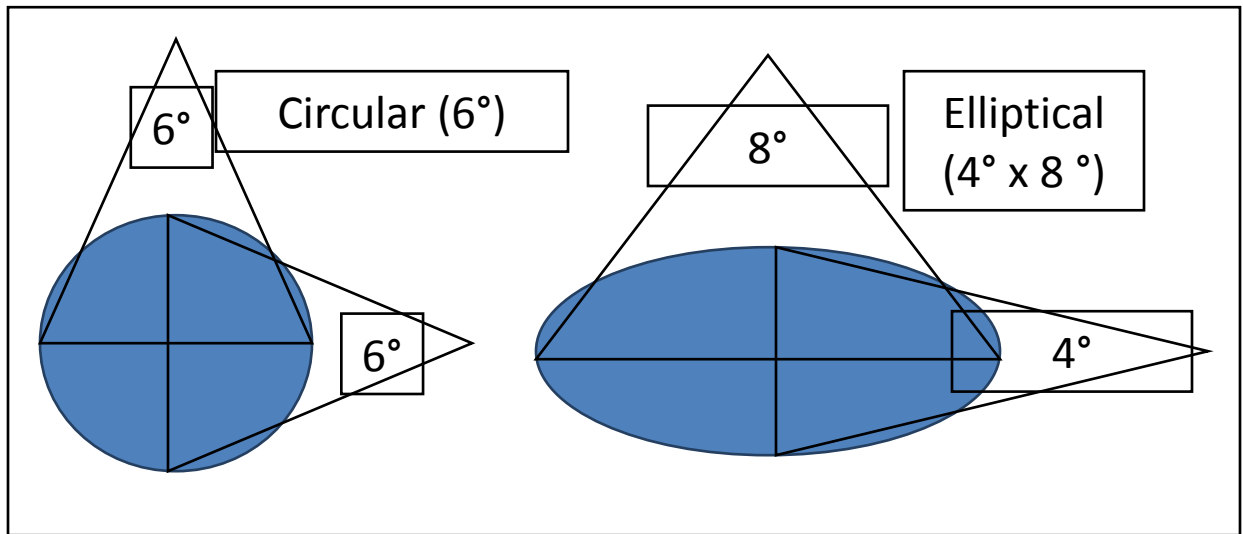


Figure 10. Cross section of circular and elliptical beams. At all ranges, the elliptical is shorter (increased effective range in shallow water) and wider (more echoes from passing target).

A hardware failure in August resulted in a two week gap in data collection on one side of the river, resulting in another change in aim when this transducer was replaced. The split-beam systems were removed from the river on 18 November.

Several approaches using an acoustic imaging system (DIDSON) were tested for species validation and data extrapolation (see Section V). The DIDSON (high frequency, 1.1/1.8 MHz multibeam SONAR) is able to image fish and other targets, within 40m range, in dark or turbid water. The first approach was sampling with the DIDSON mounted just below the surface of the water (from an anchored boat) and aimed toward the bottom. However, maintaining the boat in a fixed location at the surface was not possible. As such, the images collected could not be geo-located (particularly within the acoustic curtain) and background subtraction to highlight fish was not possible. Therefore this sampling design was discontinued and bottom deployment was tried.

The bottom-deployed approach involves putting the DIDSON on a tripod with a pan/tilt assembly on the bottom of the river from an anchored boat. This is done at 3-4 evenly spaced points across the HamBrew transect. At each point the GPS position is recorded and the

DIDSON is aimed perpendicular to water current to record passing fish on either side. This process is repeated at multiple, 3-4, points across the transect throughout the day (8-10 hours). Bottom deployment allowed three advantages, geolocation of the DIDSON (and detected targets), greater sample range, and the ability to subtract the fixed background to highlight moving fish. Bottom deployment transects were conducted every other week from May through August. Longer-term fixed deployments of the DIDSON were also conducted on two occasions to determine if this application was better for acoustic signal validation (Section V).

### ***b. 2011***

The preceding, 2010 field season (April – Nov) was a trial-period with the BioSonics equipment. Based on our research with American shad (Section III) and comparison of two beam geometries at our study site (Figure 10) we decided on 200 kHz elliptical ( $4^\circ \times 8^\circ$ ) transducers for both sides of the river. The combination of lower frequency and narrower vertical beam angle ( $4^\circ$  vs.  $6^\circ$ ) ensure quality data at maximum range. Also, the wider horizontal beam angle ( $8^\circ$  vs  $6^\circ$ ) enables individual fish to be sampled for a longer duration, producing better tracks of fish (i.e., more pings per fish, see Section IV.a. for more details) and more reliable target strength information (which can be used to validate acoustic target for some fish species). In 2011 these transducers (and associated components) were installed on 29 April and were in the water until 9 December.

A second major improvement in 2011 was establishing a wireless network between the two systems using Waterfront Marine's internet service. Prior to establishing this network, the systems were subject to power outages and hardware issues that went undetected for several days between visits. These systems can now be remotely accessed at any time from any internet-connected computer, minimizing system down time and loss of data. The internet connection also synchronizes the systems' clocks, ensuring accurate comparison between the two datasets. Finally, this remote connectivity provides real-time information on fish activity at the study site to inform scheduling of additional sampling activities, especially for target validation and taxonomic identification.

Bottom deployed transects with the DIDSON were conducted every other week from May through August and longer-term fixed deployments of the DIDSON were also conducted on three occasions (detailed in methods in Section V).

## **III. American Shad Sensitivity to Acoustic Sampling**

American shad (*Alosa sapidissima*), among other Clupeidae, are capable of detecting sounds close to those frequencies preferred for SONAR application (Mann et al. 1998). Based on this and discussions with other researchers we expected there could be some avoidance of the river section ensonified with our equipment. Representatives at BioSonics, Inc. acknowledged the potential for avoidance but suggested it could be related to the audible clicking sound created by the transducer, distinct from the intended ultrasonic transmission for detecting targets. This click is reduced by decreasing the source level (intensity) of the ultrasonic transmission and BioSonics, Inc. modified our SONAR systems to include a hardware switch for this purpose.

During 13-16 May 2010 and 3-6 June 2011 we examined the affect of split-beam SONAR sampling on upstream migrating American shad in the Connecticut River (Turners Falls, MA). Utilizing a DIDSON acoustic camera, we counted the number of fish, moving through the DIDSON frame in the presence and absence of split-beam SONAR signals of three frequencies (120, 200 and 420 kHz) and of varying source levels (intensities). No behavioral response was observed in DIDSON videos when the SONAR was first energized after a control (silent) period and analysis of variance showed no significant difference in the number of fish present between treatments.

A few factors may have confounded the behavioral observations. Discharge from the Turners Falls dam, just upstream of the study site, fluctuated throughout the study period in both years. Changes in attracting flow may have been a greater factor in shad presence than any possible avoidance of our SONAR signals. Since changes in discharge occurred over a longer time period than changes in our treatments, and fish abundance varied by several orders of magnitude throughout the study, a “response index” was created that weighted values based on relative fish abundance throughout the study (Figure 11). These datasets are still being scrutinized using this response index. However, in this environment there appeared to be little behavioral response to the frequencies tested at low power. While the mean values are not significantly different, the high power setting produced the greatest variability of all treatments and we are using the low power setting in the Penobscot.

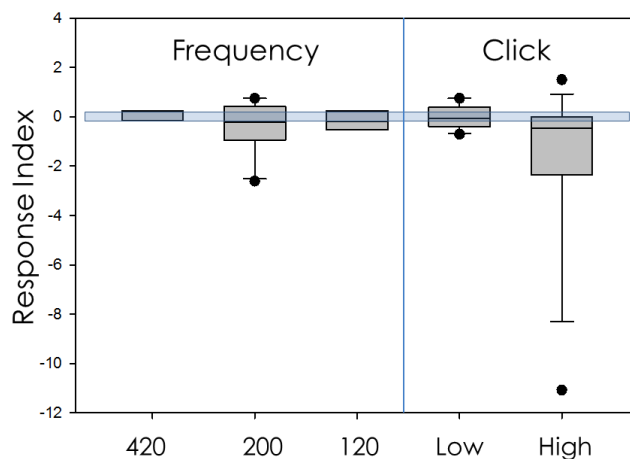


Figure 11. Preliminary results of American shad behavioral response (indexed based on control periods) in the presence of sound produced by hydroacoustic transducers of 120, 200, and 420 kHz (left panel) and grouped by treatment periods of low and high power settings (right panel).

#### IV. Estimating numbers of targets moving upstream

##### a. Tracking Fish with Split-Beam SONAR

The split-beam systems are used to generate estimates of the number of fish passing the site (i.e., fish passage). Our SONARs emit a 200 kHz “ping” for a duration of 0.2ms at a rate of 4 per

second. After each ping the SONAR listens (at 200 kHz) and records the level (or strength) of the returning sound at several hundred time intervals. The time delay is used to calculate the distance (range) the returning sound has traveled. Any reflective object within the range of the sound will generate a relatively strong return and be distinguishable against background noise. The size and composition of an object determine how much sound is reflected (Target Strength, TS). For fish, this is closely related to their size.

TS values at all ranges for every ping can be visualized as an echogram (e.g., Figure 7). Raw TS data can be filtered to remove noise or interference to reduce the echogram to those echoes that lie within a set of user-specified parameters. Remaining echoes (also referred to as single targets) are then laced together (over successive pings), using another set of user-defined parameters, into “fish tracks” or a series of echoes received from an individual fish as it moves through the beam (the acoustically sampled space).

#### *b. Estimates for 2010 and 2011*

The number of fish tracks generated using fish tracking is a subsample of the total number of fish passing through the HamBrew site because targets can be further validated and counts must be extrapolated to the entire river cross section. More refined methods for validating targets (missed fish, false positives, double counting) and extrapolating counts to un-sampled areas of the river cross section are under development (see Sections V a and b). Fish count data presented here are validated with an initial filter (cleans the data and tracks fish) provided by BioSonics, Inc. The data are not extrapolated to the entire river section.

The simplest form of validation is visual examination of the echogram (target visualization) in comparison to the number and positions (ping number and range) of exported fish tracks (from the BioSonics, Inc. processor). The intensity and angular source (relative to the transducer’s central axis) of returning sound is recorded from each sample (depth/range interval) of each ping (output sound pulse). The BioSonics, Inc. cleaner program uses a sliding average, based on user specified parameters, to estimate and remove background noise from the echogram. The tracer program is then used with the “cleaned” echograms. It isolates candidate echoes, connects them into fish traces, and outputs fish trace attributes.

Briefly, the BioSonics, Inc. processor (see Appendix 1 for further details) evaluates each ping to identify echoes from noise and then laces them together into fish tracks. For each echo that meets a set of user-defined parameters, based on pulse “shape”, amplitude, duration and angular origin (X&Y), an echo is identified as a potential fish target. The first echo identified becomes the starting point for a fish trace. Additional echoes are connected to existing fish traces or used to begin new traces based on a specified distance window and linear regression through echoes in a trace. A weighting parameter using the last four echoes allows for curvature in fish traces. As traces originate and develop through subsequent pings they are rejected or retained based on a set of filters. Filter criteria include the number of echoes, number of pings, gaps in the trace, linearity, slope and bearing. Variability in amplitude, range and velocity can also be used to filter traces. Once the tracer reaches the end of a file it exports the measured attributes (time, 3D position, velocity and physical/acoustic echo properties) of the retained fish traces. These traces were used in the data presented in Figures 12-14.

Due to changes in aim and collection parameters in 2010 we divided fish counts into three seasons. The fish counts are given as the daily proportion of season totals. This division was repeated for the 2011 data for ease of comparison between years (Figure 12). The data, as presented, are processed using the same fish counting “filter” (the BioSonics, Inc. processor, cleaner/tracer described above) for each season, and fish numbers are presented relative to the entire number of tracks counted for the season. Therefore, the proportional fish counts provided can be compared within and between years. This same filter can be used in subsequent years to provide relative fish counts annually, seasonally and at finer temporal resolutions to compare back to data already collected. It is our aim to decrease potential error in these relative counts by improving acoustic target validation techniques (Section V.a.).

Initial analyses indicate pulses of upstream moving fish following spring freshets (Figure 12) and suggest these movements predominantly occur between peak ebb and low tides (Figure 13). Plotting mean TS along with daily proportions further resolves distinct pulses of fish where abundance increases sharply with a corresponding shift in mean TS (Figure 14).

## **V. Ongoing work**

Data collected in 2010 and 2011 have been subjected to the previously described scrutinization. Additional analyses to further describe these data, i.e., improve target validation, extrapolate counts to the entire river, and verify species and species groups continue. The next few sections describe our approach to improving data analyses from 2010 and 2011 (i.e., new analyses can be applied to previously collected data) and additional data that will be collected in 2012 (under a different funding mechanism).

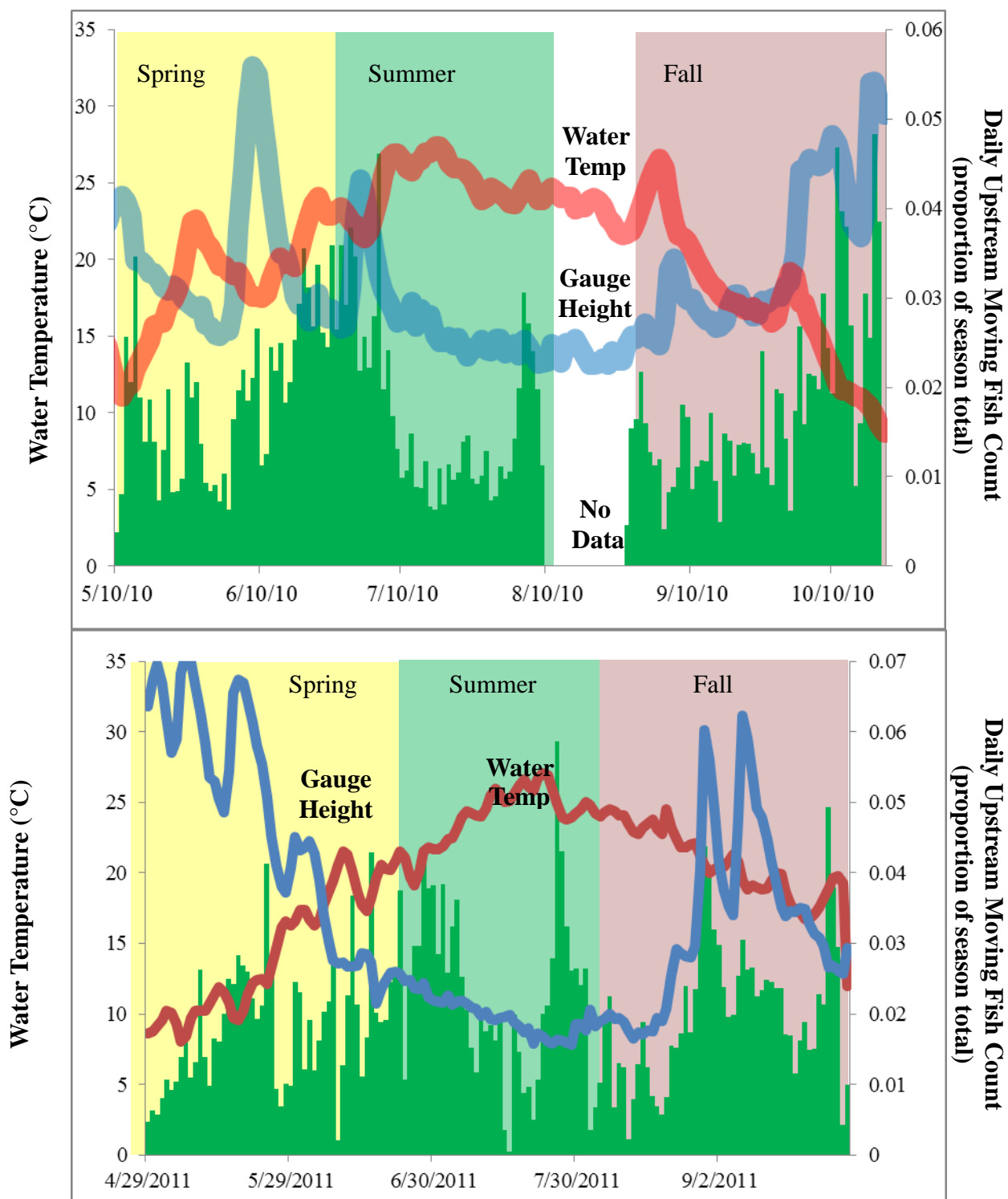


Figure 12. 2010 (top panel) and 2011 (bottom panel) daily proportion of the season totals of upstream moving fish (green bars, right y-axis) in the Penobscot River at HamBrew, plotted against river water temperature and river gauge height.

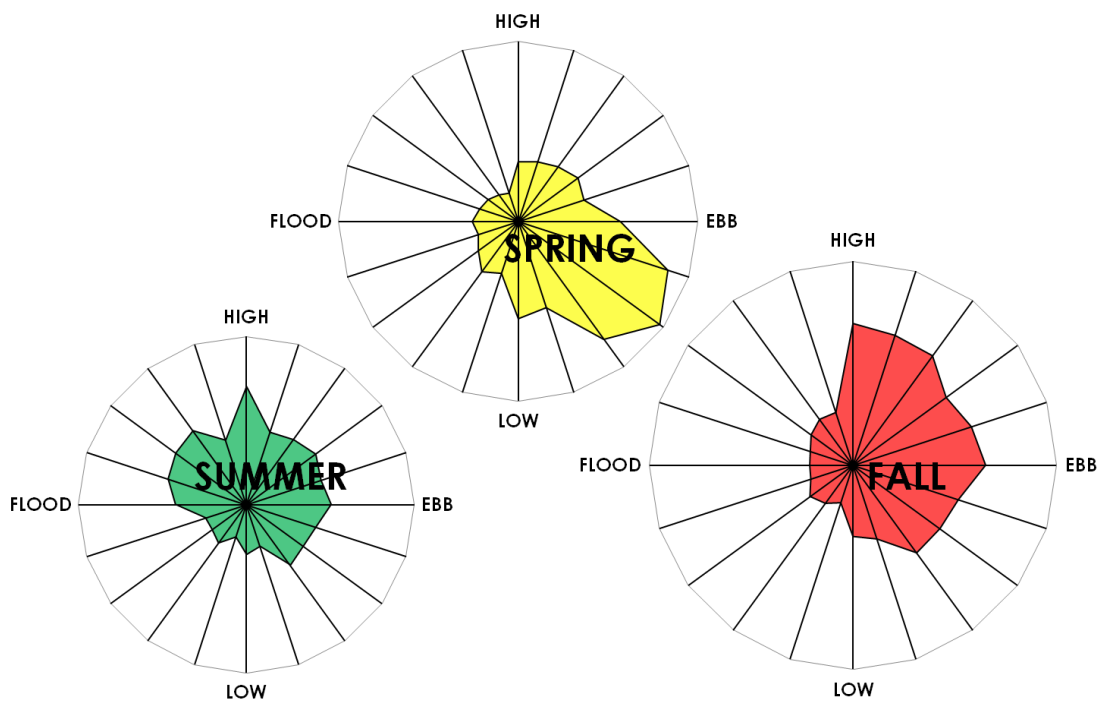


Figure 13. Polar plots showing the distribution of upstream fish movement throughout the tidal cycle for all fish tracks in a given season. Tidal stage comes from gauge height data and does not directly relate to flow velocity/ direction.

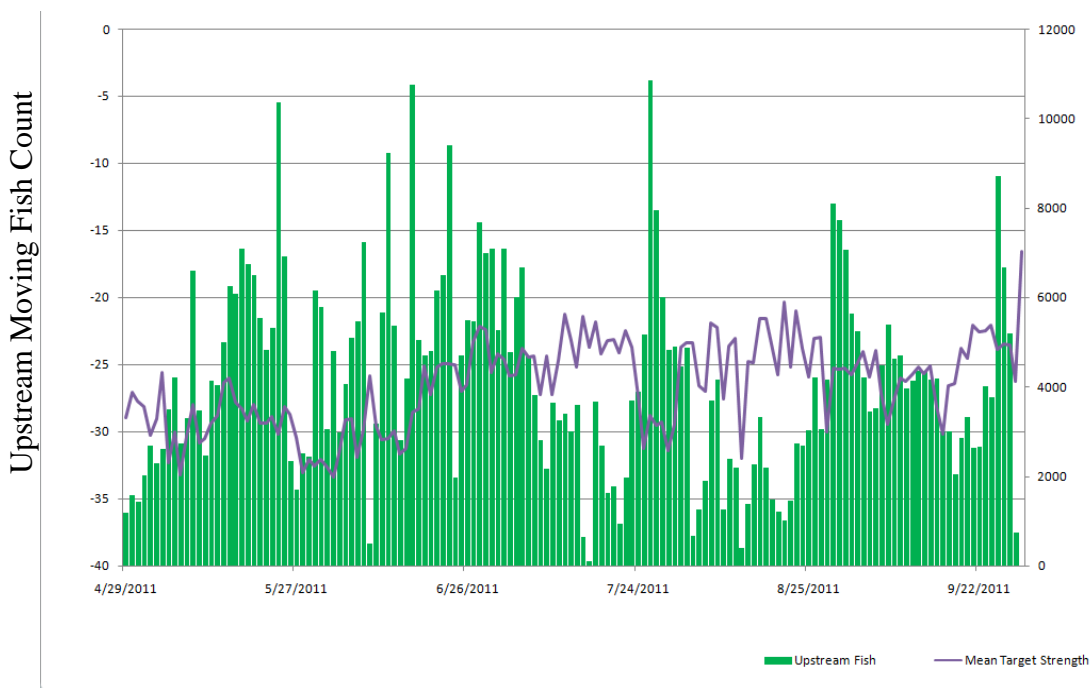


Figure 14. 2011 Daily fish count with daily mean TS values. In late July and early August of 2011 there was a marked increase in fish passage with a corresponding distinct drop in mean TS values.

### *a. Validation of Fish Counts*

Extracting fish counts from any acoustic dataset involves accounting for varying levels of error, originating from different sources. It is important to minimize processing error and adjust/correct for remaining error. The final product is heavily influenced by data collection, processing and analyses. As described above, the individual “fish” being counted are series of echoes within a larger dataset of single echoes. In this case, “fish” echoes have been selected by processing software (provided by BioSonics, Inc.) and connected together into a “fish track”. Our work to date has focused on maximizing data quality at all stages. In terms of data collection: Lower frequency transducers with elliptical beam patterns along with bathymetric and sidescan imaging of the sample site ensure that transducers are optimally located and aimed to minimize sources of noise and interference without compromising sampling effectiveness.

Data processing can involve multiple software programs. Two are: One provided by BioSonics, Inc. tailored to our project to process echograms and output fish track data automatically and Echoview (Myriax Software Pty. Ltd., Hobart), which is more user-directed/ interactive in each stage of processing. Both software packages include data cleaning/ filtering, fish tracking and automation. These software packages are used to minimize levels of error from several sources and to measure and account for remaining discrepancies.

Target validation beyond the BioSonics-processed data (cleaner/ fish tracer described above) is being explored using Matlab. Raw and BioSonics-processed data are read in and the raw echogram is displayed over a set of points identifying the initial position of each fish track generated using the BioSonics processor. The presence of a new “initial” point in the middle of a BioSonics, Inc. identified track indicates a fish that was counted more than once with the BioSonics, Inc. processor. A quantitative analysis of these points will be used to further assess the validity of tracks in the dataset. A subset of tracks will be analyzed to apply a correction factor to the BioSonics-processed data.

A second level of validation to be applied moving forward will entail using a subset of split-beam data that corresponds (in space and time) to data collected simultaneously with the DIDSON acoustic imaging system. Briefly, image data is processed to generate fish tracks where fish are viewed and measured in a video-like file. The DIDSON is effective at sampling against boundaries (surface or bottom) but at far shorter ranges than the split beam (20m vs. 100m) and although its horizontal positioning/measurements are highly accurate, it cannot resolve targets vertically (xz vs. xyz). However, position and orientation of multiple SONARs (e.g., a DIDSON and a BioSonics system) can be simultaneously analyzed using Echoview. Data are placed in a common space and synchronized so that fish tracks from both SONARs can be overlaid and examined for agreement. In 2011 we conducted several “fixed” DIDSON deployments where this unit was mounted alongside the split-beam and recording data for multiple days. These data are being used to validate split-beam fish tracks of 2011 and this technique will be applied throughout 2012.

### ***b. Extrapolation of Fish Counts***

The number of fish tracks generated using the above analysis is a relative subsample of the total number of fish passing through the HamBrew site. Counts must be extrapolated to the unsampled areas of the river cross section. For extrapolating fish counts to areas not sampled by the split beam SONARs, the bottom-deployed DIDSON transect files (Section II.a.) are processed using Echoview 5 (Myriax Software Pty. Ltd.) to generate a text file of georeferenced fish tracks and attributes. Using ArcMAP 10 (ESRI) each fish track is assigned to one of 200, 1m (longitudinal or perpendicular to the flow) segments. For each 1m segment, the total number of fish is divided by the total time the segment was sampled to generate a passage rate (fish/ hour or day; Figure 15).

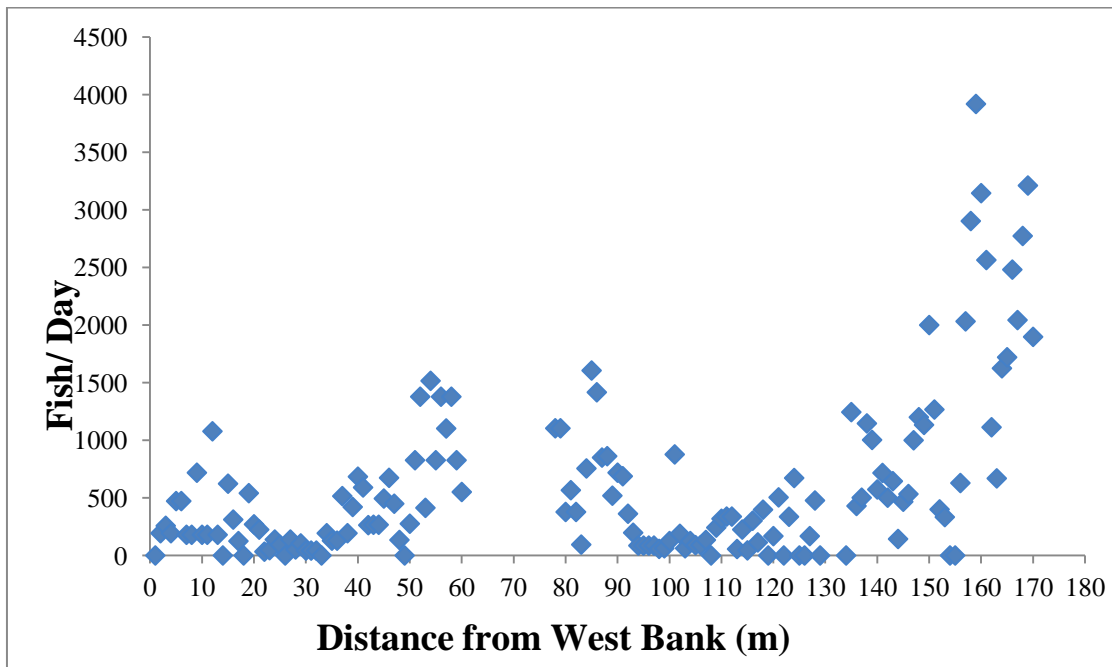


Figure 15. Representative fish rate of passage at HamBrew in each 1 m segment (parallel to the shoreline) across the river.

Transects have been conducted throughout the sampling seasons since 2010 and will continue in 2012. Over time, each 1m segment will be repeatedly sampled at different tidal stages. Fish passage rates at different stages of tide and discharge will be assessed by modeling the flow through the site (Section V.d.) and developing a functional relationship between flow and fish passage that can be applied to interpolate fish counts into segments not sampled by the split-beam SONARs (see Figures 3 or 6 for examples of unsampled areas).

### ***c. Identification of Targets and Taxonomic Apportionment of Fish Counts***

To have a better idea of what fish (species or species group) are being counted using split beam acoustics, return signals must be scrutinized and associated with fish known to be in the river at the time. The first approach to such apportionment is to use the characteristics of the returned acoustic signal. Since a fish's swim bladder (if present) is its greatest reflector of acoustic

energy the strength of the return reflection (Target Strength or TS) can be used to approximate the target's (fish's) size and (possibly species) within anatomically similar groups (i.e. anchovy and sardine, Conti and Demer 2003). With greater taxonomic and anatomical diversity the swim bladder/ fish size relationship is confounded and apportioning counts among anatomically dissimilar fishes requires additional means. Similar studies in other river systems have used capture sampling (e.g. gillnetting, electrofishing) with the observed species proportions in the capture being applied to hydroacoustic count data. Populations of endangered Atlantic salmon and shortnose sturgeon in the Penobscot River necessitate tight restrictions on capture sampling while, at the same time, present an ideal setting for investigating alternative sampling methods that minimize impacts to individual fish. However, SONAR sampling and post processing software allows us to explore various aspects of an individual target's acoustic return (e.g. target strength and pulse width). In addition, information about a target's behavior (e.g. speed, trajectory, tail beat frequency) can be extracted from the acoustic data (Mueller et al. 2010, Fleischman and Burwen 2003). These attributes, in isolation, provide little basis for species discrimination, however, by integrating and analyzing as a whole we hope to identify "species signatures" across these multiple target attributes. In addition we will integrate and synchronize multiple datasets, from a diversity of sources, using a four dimensional GIS framework (using Eonfusion software from Myriax Software Pty. Ltd., Hobart).

*Four-dimensional Cluster Analysis of Fish Tracks* - The DIDSON and split-beam data can be distilled into 4D positions (x,y,z, time) and other measured attributes of individual fish. Through 4D cluster analysis, groupings of fish that may indicate taxonomic class, schooling vs. individuals, and other behaviors. For example, a pulse of migratory fish should be discernible from background resident fish activity as a spike in fish abundance via shifts in mean TS and drops in TS standard deviation (SD). This analysis will reveal the spatial and temporal scales at which clustering occurs. For example, fish activity may be very different from one hour to the next while very similar at the same tidal stage among several days. This would result in strong clustering at periods of approximately 12 hours along the temporal dimension corresponding to a complete tidal cycle. There may also be clusters occurring at other temporal scales and perhaps certain schooling fish may cluster at particular spatial scales.

With corresponding DIDSON data, individual fish might be identifiable or at least can be measured and a length/TS equation derived. This abundance and size information, combined with documented observations of species specific seasonality/ run timing from the literature, enables some level of taxonomic apportionment of counts. Incorporating additional taxonomic information from concurrent studies increases confidence and specificity.

Data from several concurrent studies in the Penobscot are being used to corroborate abundance information, aide in taxonomic classification of counts, and will be incorporated into the 4D analyses:

*Boat Electrofishing*- Ian Kiraly (UMaine Masters student) has been conducting fish community surveys, using boat electrofishing and beach seining. These data consist of date, time, location and counts for each species observed. Our initial plans included incorporating boat electrofishing data to verify species present during specific times of the year. However, this approach was found to not effectively sample 75% of the river

habitat at the hydroacoustic site because the site is too deep. In addition, the 2010 boat electrofishing survey collected very few (<10) fish during four separate surveys in the area, confirming that this approach is not very useful for apportioning acoustic targets to species in this section of the river. We will continue to request the electrofishing data from this area as it is collected in the case that it may be informative in the future.

*Veazie Dam Counts* –The Maine Department of Marine Resources traps upstream migrating fish, at the top of the Veazie Dam fish ladder. The Atlantic salmon are then transported and released above Milford Dam. The catch is predominately Atlantic salmon and daily records consist of individual lengths, weights and sex. Some alewife, American eel, and sea lamprey have also been observed in this trap and their daily abundances are also recorded (Cox pers. comm.). All these species transit the HamBrew at a time prior to entering the Veazie Dam fish ladder. A lag time for transit between HamBrew and Veazie will be calculated and the acoustics dataset will be scrutinized for the passage of these species.

*Lower River and Estuary Study* – Since 2011 researchers from NOAA's Orono field office have been conducting mobile acoustic and netting surveys in the lower Penobscot River and estuary. Acoustic surveys are accompanied by mid-water trawl sampling and together provide an estimate of species specific abundances, sizes and acoustic target strength distributions. Fyke and seine netting along shore also provide species composition and size information. Target strength histograms are produced and compared with histograms of fish lengths from concurrent mid water trawls. Concurrence of these target strengths with those collected at the HamBrew site will be assessed by generating similar target strength echograms for similar sampling durations and analyzing correlations with the samples collected downstream. It is likely this approach will be effective when there are distinct schools of fish that remain together during their upstream migration. If a clear relationship can be established this will also provide an initial estimate of the travel time/lag between HamBrew and downstream sampling locations.

*Acoustic, Radio and PIT Tag Data*- Various forms of telemetry and fish tagging are being used by UMaine, DMR and NOAA in the Penobscot River. Individual fish are tagged and tracked in the Penobscot River Watershed and beyond. Species tagged concurrently with this study have included Atlantic and shortnose sturgeon, Atlantic salmon (smolts and adults) and American shad. Technology exists to triangulate acoustic and radio tags as they pass through a site using multiple receivers in close proximity (e.g. Vemco's VRAP system). However, the spatial dimensions of the HamBrew site required an extensive array (at least 6 receivers and several sentinel tags) and cost of the proprietary data processing precluded this approach. We are however making use of outside fish movement data generated by existing receivers/ arrays. Several receivers are located upstream and downstream of HamBrew. As such, transit time between receivers can be used to determine when individuals may have moved through the acoustic curtain and these individual tracks can be identified in the acoustics data.

#### ***d. Modeling Flow Velocity and Direction***

Since we are observing a fluid environment from a fixed location (Eularian frame of reference), measures of fish speed and trajectory are relative to the river hydrology. While previous studies in other river systems have benefited from relatively stable, unidirectional river flow, due to the restricted depth of the river the hydrology at the chosen location is not as predictable. As mentioned earlier, tidal influence and bidirectional flow presents an additional challenge and opportunity for innovation.

Hydrologic variability is primarily dictated by seasonal river discharge but is further compounded by a semidiurnal tidal cycle. The river flow across the HamBrew transect will be modeled using discharge and tidal data. Modeled data will be related to velocity and direction as measured with a boat mounted ADCP. Several surveys have been conducted in transects across the river multiple times over full tidal cycles. Additional surveys must be conducted to validate model results and apply the results to the fish count acoustics dataset to further improve target validation and extrapolation.

### **VI. References**

Conti, S. G., and Demer, D. A. 2003. Wide-bandwidth acoustical characterization of anchovy and sardine from reverberation measurements in an echoic tank. – ICES Journal of Marine Science, 60: 617–624.

Fleischman, S. J. and D. L. Burwen. 2003. Mixture models for the species apportionment of hydroacoustic data, with echo-envelope length as the discriminatory variable. ICES Journal of Marine Science. Volume 60, Issue 3, Pages: 592-598.

Mueller, A., Burwen, D.L., Boswell, K.M., Mulligan, T. 2010. Tail-Beat Patterns in Dual-Frequency Identification Sonar Echograms and their Potential Use for Species Identification and Bioenergetics Studies. Transactions of the American Fisheries Society. 139(3): 900-910.

### **VII. Book-keeping**

#### ***a. Project PIs:***

Gayle Zydlewski, University of Maine (UMaine), School of Marine Sciences  
1 month salary annually

Patrick Erbland, University of Maine, School of Marine Sciences  
12 months salary annually

#### ***b. Part-time assistance:***

Sebastian Velez (3 months summer salary 2010, paid by UMaine SMS)  
Matthew Dzaugis (1 month summer salary 2010, paid by UMaine SMS)

Alexander Jensen (2 months summer salary 2011, paid by ORI)  
Brittney Fleenor (1 month summer salary 2012, paid by UMaine)

***c. List of items worth over \$300 (purchase value listed)***

Biosonics Hydroacoustic Systems	
2 BioSonics DT-X with 200 kHz transducers :	\$86,000
1 Mobile BioSonics DTX with 420 kHz transducer:	\$43,000
Dell Desktop	\$1,200
Vemco VR2W (2)	\$2,800

## VIII. Appendix 1: Description of BioSonics data processing

Raw SONAR data consists of the intensity of returning sound from each sample (depth/range interval) of each ping (output sound pulse). Split beam SONARs (in contrast to single beam) also measure the angles (given as X and Y) between each sample's source and the transducer's central axis, this is also recorded (Figure A.1).

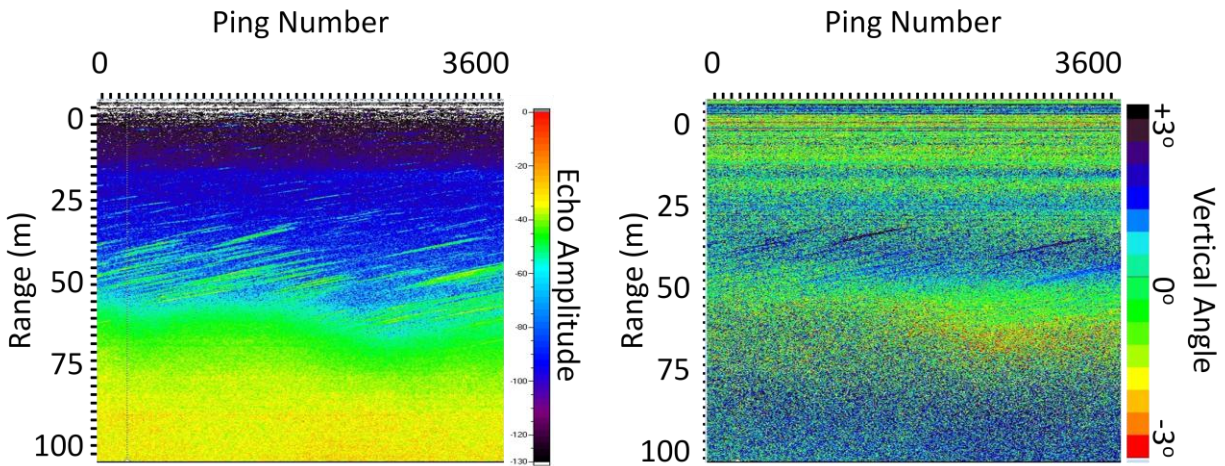


Figure A.1- An example target strength echogram (left) and vertical angle echogram (right). Fish traces appear as diagonal green lines and surface noise appears as a green/ yellow area in the target strength echogram. The vertical angle echogram shows that the fish traces and surface noise are at a positive vertical angle (blue to black) relative to background noise (green).

The BioSonics, Inc. 'cleaner' program removes background noise from the echogram (Figure A.2) and is controlled by four parameters:

1. Number of pings for cleaner core- A cleaner core is composed of individual acoustic parameter averages for each sample (range) across the specified number of pings. A smaller value is more adaptive to variable noise while a larger core is less likely to degrade or remove fish tracks.
2. Cleaner core refresh rate- Interval for calculating a new cleaner core (number of pings).
3. Decibels, above core, to subtract- Cleaner core averages plus this decibel value is subtracted from echogram.
4. Multiplier for smoothing core- The cleaning process is prone to leaving thin lines at the edges of structures, known as scintillation. This value helps to remove or reduce scintillation.

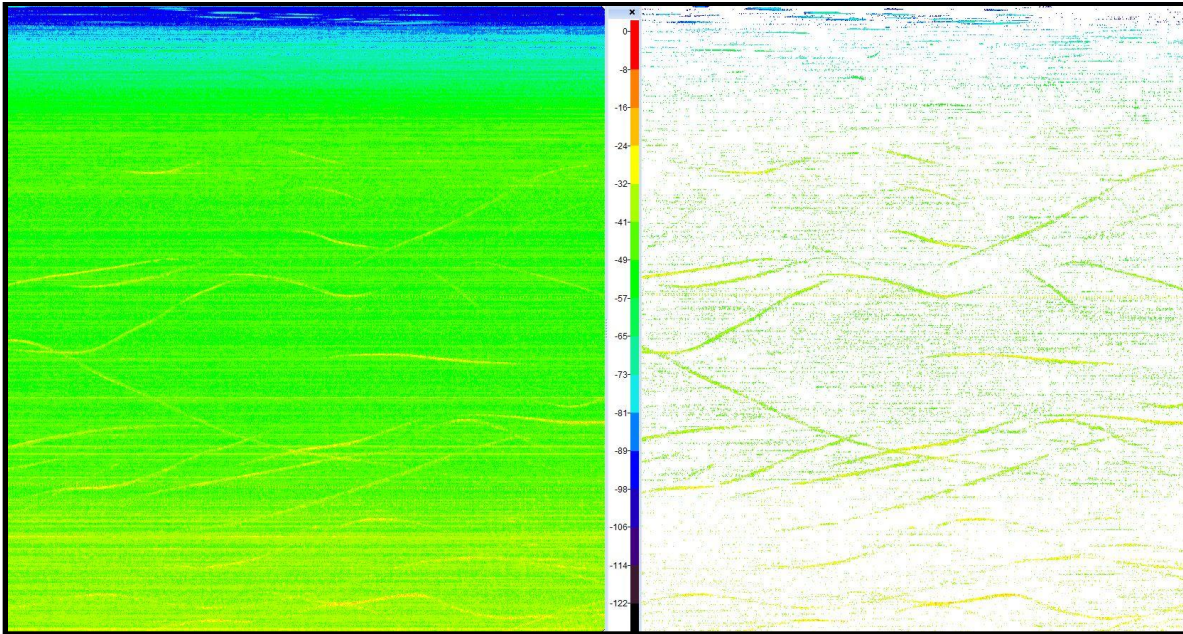


Figure A.2. An example raw (left) and cleaned (right) target strength echogram. Notice that the fish traces are retained at their true amplitude values while most of the background is zeroed out (white).

Fish tracking can be applied to raw or cleaned files. Candidate echoes are isolated and connected into fish traces, and fish trace attributes are output. There is no user interface and input parameters are defined within a separate configuration file. There are three major processing steps in this program:

1. Echo Identification - Each ping of a file is analyzed and echoes that meet a set of user defined parameters (from a configuration file) are identified. Processing criteria are based on pulse “shape”, amplitude, duration and angular origin (X&Y) (Figure A.3).
2. Fish Trace Formation - This is a two dimensional (Time x Range) tracker and angular (X&Y) data are not used. The first echo identified becomes the starting point for a fish trace. Additional echoes are connected to existing fish traces or used to begin new traces based on a specified distance window and linear regression through echoes in a trace (Figure A.4). A weighting parameter using the last four echoes allows for curvature in fish traces.
3. FishTrace Filtering - As traces originate and develop through subsequent pings they are rejected or retained based on a set of filters. Criteria include the number of echoes, number of pings, gaps in the trace, linearity, slope and bearing; variability in amplitude, range and velocity can also be used to filter traces.

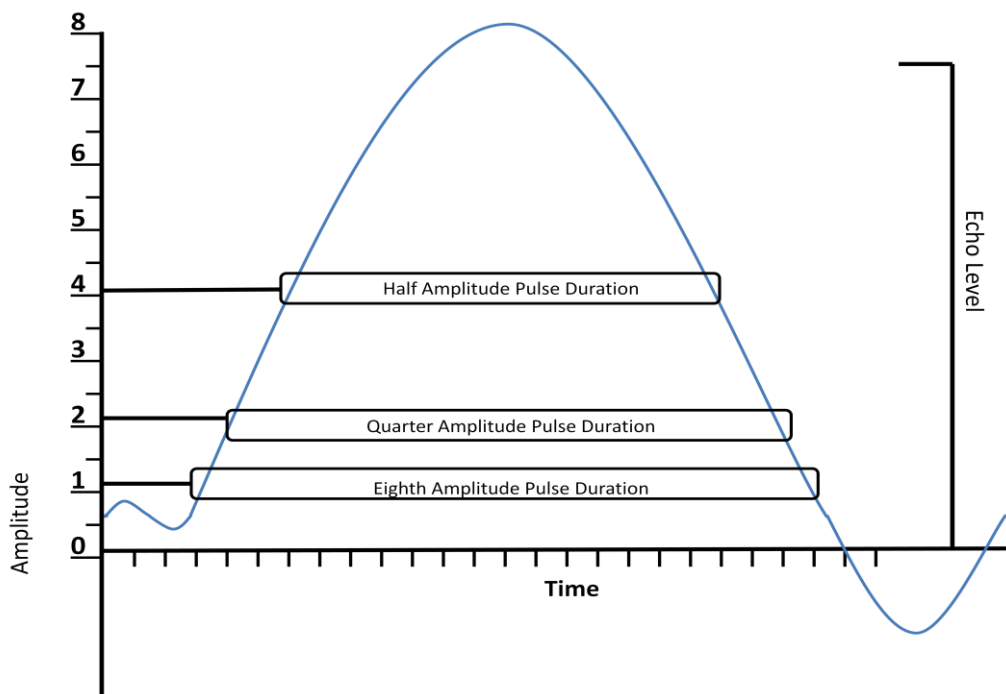


Figure A.3- Representative waveform of returning acoustic pulse showing some of the criteria used to identify candidate echoes for trace formation.

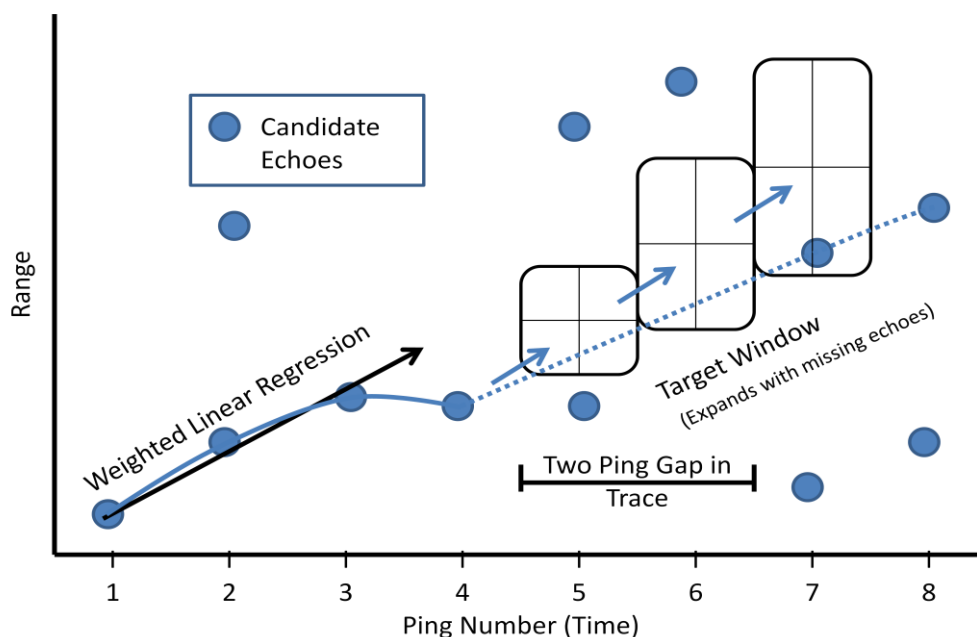


Figure A.4- Example trace formation sequence. A weighted linear regression of the preceding four echoes projects a target window (size defined by user) into ping 5. If no candidate echo occurs in this window, the window is expanded (by a user defined percentage) into ping 6 along the regression line. This process continues into ping 7 where a candidate echo is found within the target window and added to the fish trace. Setting the maximum ping gap to 1 would have terminated the trace at ping 4 and setting the minimum trace size to 5 pings would cause this fish trace to be rejected.